MASS PRODUCTION

Towards Multidimensional, Real-time Feedback in Early Stages of Urban Design Processes

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Abstract. Urban design, especially in its early stages, focuses mainly on massing studies rather than architectural detail or engineering. Traditional urban design workflows involve a mix of sketching and modeling. However, the back and forth between the sketching-modeling loop is typically fairly time-consuming, resulting in a reduced capacity to iterate efficiently over design concepts, even in their digital form. In this paper, we present a workflow for producing digital massing tests from hand-drawn sketches. The goal of Mass Production is to help quick iteration on volumetric design enhanced by real-time feedback on quantitative and qualitative parameters of the model, thus helping designers make better informed decisions on early stages of urban design processes. The architecture of the proposed workflow consists of three main elements: a tangible user interface (UI) for designer input, a real-time dashboard of diagrams and models for massing analysis, and an augmented reality (AR) environment for enhanced feedback on design form and shaping. In this research, Mass Production is tested in different design scenarios, a discussion about the future and its impact is presented, including emerging technology while keeping traditional workflows.

Keywords. Urban Design; Massing Study; Augmented Reality.

1. Introduction

Due to the scale and goals of urban design, massing study is often the start point and key of the whole urban design process. The process of massing study, both in academia and in practice, features a linear protocol: conceptual sketching on paper, allowing quick but rough illustration of design ideas, followed by 3D digital modeling, offering more precise volumes with quantitative examinations, and physical 3D modeling providing a sense of scale on site. Although each step aims at specific design goals, the back and forth between sketching and modeling is generally time-consuming, slowing down the pace of design iterations. Numerous efforts have been devoted to optimizing this process.

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We present a workflow for producing digital massing tests from hand-drawn sketches. This project aims to help quick iteration on volumetric design enhanced by real-time feedback on the model's quantitative and qualitative parameters, thus assisting designers in making better-informed decisions on early stages of urban design processes.

Firstly, sketching is the native language of designers. It allows the most freedom of expressing design ideas, but at this stage, designers can only imagine an incomplete picture of how the 2D sketch looks in volumetric form. We present a graphical input interface on tablet devices where sketching's freedom and fluidity are mostly maintained. The 2D sketches can be 'translated' into geometry data for 3D digital models in modeling software. In this workflow, quick sketch and precise massing feedback happen simultaneously, facilitating more accuracy in sketching and providing evidence for selecting the most suitable massing typologies (tower, courtyard, slab, mat building, etc.) for specific projects. While most computational urban design tools aim at optimizing statistical parameters such as FAR, open space ratio, density, sunlight, etc., this real-time correspondence between 2D sketches and 3D digital modeling only assists designers to quickly experiment with their own design ideas instead of developing the massing form from a dataset and making decisions for designers. In this sense, we try to preserve designers' dominant role in the design process and encourage them to determine the massing form with real-time massing parameters only as a reference.

Furthermore, massing study in urban design is not only about qualifying for objective specifications but also pursuing a subjective sense of scale and form, which is traditionally studied by physical models. The time delay between early sketches and physical model presentation considerably slows the design iteration. What if designers can perceive on-site massing volume and get the sense of scale in the most initial stage possible? The recent mobile Augmented Reality (AR) technology "has the potential to offer new opportunities for co-designers as a new design platform where the physical and visual models are superimposed during the architectural massing study" (Gül, 2017). The geometry data gathered from tablet sketches is also "translated" into augmented massings that can be inspected by the designers while they are sketching. This AR on-site volume helps designers study how the design fits into the context in a more visible and "tangible" manner. In conclusion, the connection we build between the sketching and modeling removes the time delay between the two steps. With objective and subjective modeling feedback at the earliest design stage, both the efficiency and experience of massing study are improved.

2. Background

Existing digital design tools can be described under three main categories. The first one is the parametric model and information modeling. It is possible to have a developed rule-based computer-aided urban planning and design platform with an implemented theoretical model. It can formulate urban programs, generate design according to urban grammar, and evaluate the generated design (Duarte et al. 2012). The second is developing urban form from a parameterized dataset. In this sense, Shen et al (2020) and Jinmo et al (2020) have for instance experimented with the generation of urban patterns with machine learning. The third is visualization, collaboration, and interaction. Work in this direction involves exploring tools to enable visual management of strategies and risks, assisting decision-making with knowledge models, and enhancing participatory design by evaluating stakeholders' needs (Kunze et al. 2012).

While computer applications provide designers with extensive pre-defined functionalities in high precision and sufficient details, traditional tools are preferred because of their flexibility, speed, and intuitive interaction. In practice, many design works are drafted by traditional tools in the early stages and then completed by digital ones in later stages (Aliakseyeu, Martens and Rauterberg, 2006). Based on these ideas, we propose to rethink the role technology plays in our design process, from fully automated, data and computer-driven to human dominant with computer-assisted and data-informed.

AR technologies are reliable and can be deployed on mobile devices. Such technologies support the visualization of building on-site and aid design and construction design in the architectural domain (Billinghurst and Henrysson, 2009). The study also proved the benefits of using AR in landscape education. AR can offer individuals a new learning experience by demonstrating the theory on a real-world site (Jeremy and Lawson, 2020). It helps reduce the time and effort of building real physical models but conveys similar if not the same sense of scale.

Compared to existing 3D modeling software often used by architects and urban designers such as SketchUp (SketchUp, 2021) and Rhinoceros 3D (Rhinoceros 3D, 2020), Mass Production aims to build a more intuitive workflow for designers, focusing more on the massing stage of urban design, and with less functionalities. It allows a more intuitive way of input by sketching on touch screens of tablets and makes it easier to perceive building volumes in AR. Though Mass production does not support complex operations on massing, the digital model it produces could be exported and modified in other 3D modeling softwares.

3. Methodology

Mass Production consists of three main components: a graphical user interface that takes user's input, a bespoke geometry-processing unit for translating user's input to a 3D digital model and producing necessary diagrams to provide statistical design feedback, and a mobile Augmented Reality section letting user test the massing in physical model scale and get a sense of aesthetic design feedback (see Figure 1).

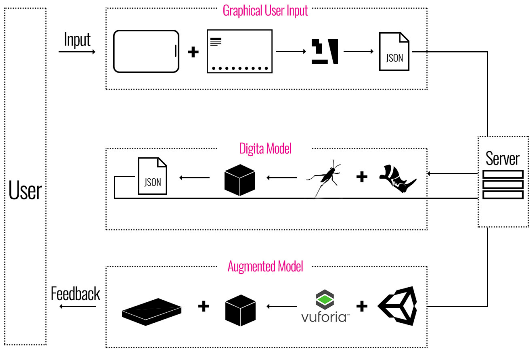

Figure 1. Diagram of workflow, integrating Graphical Input Interface, Digital Model and Augmented Model .

3.1. CONNECTION

The three elements of this design framework communicate via WebSockets (WebSocket, 2020), a standard network protocol, allowing users to connect multiple devices over local or world networks, opening the possibility for team collaboration. By setting up the three parts of our tool as WebSocket clients and connecting to the same server, information is stored in JSON format (ISO/IEC 21778:2017, 2017) and transmitted among them. The geometry-processing unit is implemented using Rhinoceros 3D, a NURBS-based 3D modeling software, and its plug-in Grasshopper 3D (Grasshopper 3D, 2020), a visual algorithmic modeling tool. This component receives messages from the graphical input interface about the user's input and sends 3D digital model information to the AR component. The details of this communication will be presented in the next sections.

3.2. GRAPHICAL INPUT INTERFACE

A digital sketching interface was developed for a tablet device for the user input, with drawing tools targeting specifically urban design parameters. The technology stack for this UI is platform-agnostic and can be run on any touch-capacitive device. We try to keep the feeling of the way urban designers sketch on trace paper, intuitive, low cost, and easy to use, but enhance it to be editable and responsive. To make our tool simple and let users concentrate more on design, the elements are kept as simple as possible: a canvas that allows users to sketch on, some buttons taking urban design parameters and a display area to inform users what they're drawing.

The canvas is organized by layers. A base site plan is displayed on the bottom layer, with the site boundary outlined by red lines. Users can add as many layers as desired and draw on them, except the base one. Layers can be toggled on and off to make it convenient for users to test massing in batches. Users are able to draw two kinds of shapes: quadrilateral and free forms. In quadrilateral mode, users are required to draw four lines, then a quad polygon will be generated automatically based on our calculation of intersections. While in free form mode, every continuous move of the pen will close automatically and be recorded as a polygon. In both modes, a void shape could be created to subtract it from other buildings. This allows more flexibility in massing combination. After a shape is formed, we could drag it to different locations or delete it to revise the design according to the feedback we received from other parts of this tool. As rectangles are one of the most common and essential shapes in urban design, we offer an orthodiagonal mode that constrains users to draw purely vertical and horizontal lines only.

The other input information needed is urban design massing parameters. Users are required to provide two parameters. As we draw sketches building by building in plan, height is necessary to translate it to 3D model. Three height options (low, middle, high) are provided per the user's selection. These are considered enough for the early stages in urban design. A building program is also requested, allowing users to choose from retail, residential, and office buildings. This will be used in statistical calculation and visualization steps later and may be useful in further development. Figure 2 shows the Graphical Input Interface.

Figure 2. Graphical Input Interface, Upper Left: Tower typologies, Upper Right: Simple urban design plan sketches, Lower: Courtyard typologies sketch with toggling void layers for design comparison.

After each operation is complete, our user input interface will broadcast information of all current active buildings to the server. The message will then be echoed to the geometry-processing component. Operations are defined as a shape being formed, deleted, or dragged, or a layer being toggled on or off. Where applicable, messages contain points for each shape, corresponding height, layer, and building program.

3.3. DIGITAL MODEL

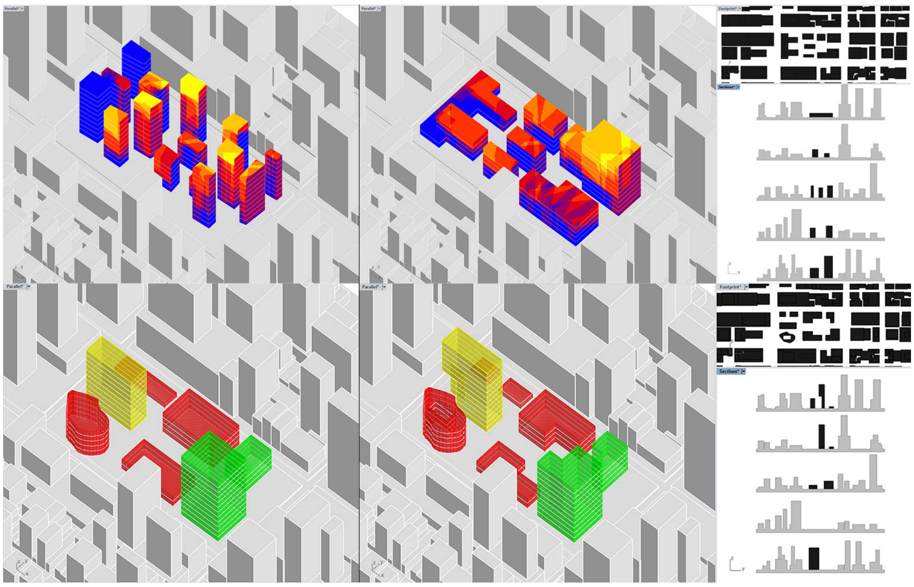

Figure 3. Digital Models and Analysis, Upper Left: Tower typologies with sunlight analysis, Upper Right: Simple urban design massing with sunlight analysis, figure and ground and serial sections, Lower: Courtyard typologies massing with toggling void layers for design comparison.

The aim of this work is to translate the sketches into 3D models for further detailed development and provide statistical figures and analytical diagrams for feedback. As both models and diagrams should allow further development, modification, and visualization, the Rhinoceros and Grasshopper platforms were chosen for their wide usage. This setup enabled performing advanced geometry manipulations, such as complex Boolean operations, creating buildings in different layers, and making the tool compatible with many existing analysis extensions.

Polygons of each building and void footprint are created from points with messages fed through our server. The footprint then is extruded according to the height option the user selected. Height is initially randomly chosen from 1-3 floors, 4-6 floors, and 9-12 floors, corresponding to low, medium, and high, respectively. This randomness happens within a small range and is intended for making the massing visually appealing, not affecting the production to a significant degree. The tool then computes Boolean operations and subtracts void spaces from buildings of other programs. Buildings belonging to different programs will be displayed in different colors.

Once the 3D models are ready, the tool analyzes the massing and provides design feedback. Pitts's (2012) work concentrates on statistical figures such as FAR, GFA and density. Guthrie (2003) highlights IBC (International Building Code) that "all services provided by an Architecture office include: Programming, Space Diagrams, Site Development Planning, Site Utilization Studies, Utility Studies, Environment Studies, and Zoning". We combine existing research and tools, as well as our own experience as urban designers, and propose the following diagrams to be our output: figure and ground diagram showing how the massing pattern co-exists with the context, serial sections to illustrate if the massing fit into surroundings in the vertical dimension, and sunlight analysis to provide environmental studies feedback (see Figure 3). We also annotate statistical parameters (FAR, building density, and GFA) in our tool to let users be informed if the site is being fully used.

Information of 3D models is delivered to the AR part through the server. Model of each building (Vertices, Triangles, and Normals) and its height are stored in JSON format. Below shows an example of a message.


```
{
  "objectType": "geometryCollection",
  "data": [
    {"objectType": "mesh",
     "faceIndice": [1, ..., 4],
     "vertexCoord": [251.0, 414.7, ..., 420.3, 0.0],
     "program": "office"},
  ]
}
```


3.4. AUGMENTED MODEL

Traditionally, urban designers and architects make physical models to get a sense of scale, how proposals would fit into the context and get visual feedback from the design. Shin et al (2013) discuss how virtual 3D models and AR are both expected to support the scene imagination, while "the AR representation for non-existing buildings in an existing environment presents the seamless scene of the 3D models combined with the real site on the display". Our tool tries to utilize the power of AR technology to replace the role of traditional physical massing models. We choose Unity (Unity (game engine), 2020), a cross-platform game engine, and Vuforia (Vuforia Augmented Reality SDK, 2020), an augmented reality software development kit, as platforms for AR deployment for its easy implementation and wide use.

A physical site model is required as the existing environment to help users build a sense of scale and site conditions. The model should be scanned and set as the target object within Unity. Unity also serves as a WebSocket client and receives messages from the Digital Model section about massing. Our own script will reconstruct the massing and in designated locations within the scanned site in real-time. With an AR device connecting to Unity, when the device detects physical site models, user's design proposals will pop up where the physical site is located. Similar to the digital model, massing will be colored according to their program (see Figure 4).

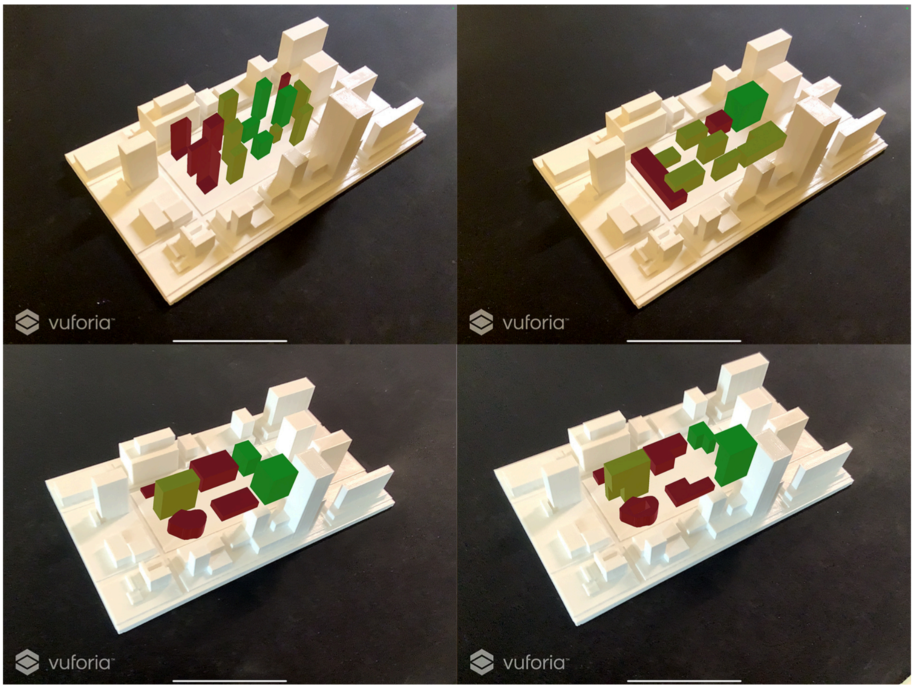

Figure 4. Augmented Models, Upper Left: Augmented tower typologies in physical model, Upper Right: Simple urban design massing, Lower: Courtyard typologies massing with toggling void layers for design comparison.

4. Results

With all three parts assembled together, Mass Production is an effective tool to translate urban designer's sketches into digital models, diagrams, and AR models in real-time and provide seamless visual and statistical feedback about urban design massing. The framework was showcased at an interactive exhibition (see Figure 5) under the theme of Computational Design at Harvard University Graduate School of Design to audiences from different fields such as urban design, community design, design technology, and data science in both academia and industries. Mass Production was also tested by authors' cohorts at school who major in architecture and urban design.

Figure 5. User Demonstration during the exhibition.

The feedback was generally positive, while some suggestions were inspiring. Users working on community engagements suggest that Mass Production could be used in participatory design as it's friendly to local residents who have no experience in design software. They only have to use tablets and pens after technical specialists set up the devices and software. The limitation users suggested was that some designers are not familiar with the programming and tools we used. They suggested Mass Production to be further compacted to avoid unnecessary setups and limit the software.

5. Discussion & Future Work

Along with algorithms, machine learning and VR/AR are widely applied in urban design fields, as urban designers, it's essential to understand these technologies and what advantages they could bring to our design with a critical view. Mass Production's goal is to keep the good and old way we practiced over the past decades but accelerating it by introducing computational and AR tools into this process. With mixed physical site models and urban design massing in augmented reality, the traditional sketching-modeling loop's feedback time has been reduced to almost zero. Mass Production makes the whole process faster and better as it makes both drawing and modification on sketches more convenient and accurate. It allows remote cooperation because of the networked communication, which could have an increasingly important role in contemporary contexts of social isolation. Mass Production is economical and environmental friendly as it helps to make the process consume less paper and model materials while it doesn't require expensive devices. We hope this tool could help designers concentrate more on the design itself by rapidly producing massing tests.

We plan to continue developing this tool to incorporate new techniques, equipment, and software mainly in two aspects: improving the user experience and adding more functionalities. While this tool aims to replace and accelerate traditional sketch-model loops, we try to make the interface, setup and experience as simple as possible. Our tool currently involves three software and at least two devices, which makes it sometimes cumbersome to switch between devices/software. By integrating some available software such as Fologram (Fologram, 2020) or developing our own app, the workflow will be more rational and fluid.

We also envision the completion of our feedback loop. Currently, the sketch interface changes could influence the final AR model, while users can't manipulate the AR model directly. We are considering adding features that allow users to modify AR models directly with hand tracking or other available technologies. The program, the input parameter users choose for each building, is not fully utilized right now. Instead of pure visualization purposes, different features could be visualized such as architectural style, facade design, or typologies to push this tool a step further into urban design phases.

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